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ScienceDirect
Energy Procedia 140 (2017) 495–505
Energy Procedia
www.elsevier.com/locate/procedia

AiCARR 50th International Congress; Beyond NZEB Buildings, 10-11 May 2017, Matera, Italy

Retrofitting under protection constraints according to the nearly Zero Energy Building (nZEB) target: the case of an Italian cultural heritage's school building.

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Abstract

The subject of this study was the definition of criteria for intervention on school buildings, protected by the Italian Cultural Heritage Code, with the aim of upgrading according to the target nearly Zero Energy Building (nZEB). The tasks required to carry out the study have foreseen the identification of a case-study representative of a common historical school building typology. Than the definition of retrofit measures has been set to meet the nZEB requirements as defined by the National implementation of the EPBD Recast, while complying with the protection constraints. Finally, the cost-effectiveness of the various interventions was also evaluated.

Peer-review under responsibility of the scientific committee of the AiCARR 50th International Congress; Beyond NZEB Buildings.

Keywords: historical school building retrofit; building retrofit compliant with protection constraints; nearly Zero Energy Building retrofit; cost-effectiveness of building retrofit; cultural heritage's building retrofit.

1. Introduction

Energy efficiency in buildings is an important objective of energy policy and strategy in Europe since the building sector accounts for about 40% of final energy consumptions in the EU.

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Peer-review under responsibility of the scientific committee of the AiCARR 50th International Congress; Beyond NZEB Buildings
10.1016/j.egypro.2017.11.161

The recast of the Energy Performance of Buildings Directive [1] requires the EU-Member States to define nZEB (nearly Zero Energy Buildings) energy efficiency requirements and standards. The nZEB is a building with very high energy performance where the nearly zero or very low amount of energy required should be extensively covered by renewable sources produced on-site or nearby.

The current Italian building code and national definition of the nZEB [2] requires constructing new buildings to be built as nZEB starting from 2021 onwards (while public buildings from 2019). Considering that energy efficiency renovation of buildings is a priority for Italy, national legislation set the same energy performance requirements of new buildings for those existing buildings undergoing a major renovation, as the EPBD Recast recommends.

Most of the Italian buildings have been built during the three decades following the World War II. Nevertheless, the national architectural building heritage also consists of huge and widespread amount of previously built constructions. These buildings, although not always characterized by a monumental importance in themselves, determine the historical identity of unique urban contexts.

The national public building stock, built over seventy years ago, in fact, is amenable to protection and it is a large part of the entire building sector.

In particular, the Italian school buildings are 52,000: of which slightly less than 80% date back to more than thirty years ago and almost 20% to more than seventy [3],[4].

The renovation of these buildings requires targeted technical solutions, even in the case of scenarios regarding the improvement of the existing stock's energy efficiency.

The Code of Cultural Heritage and Landscape [5] states that the cultural heritage cannot be destroyed, degraded, damaged or adopted for uses that are either incoherent with their historical artistic value or affect their conservation status. Therefore, each new intervention, including the energy efficiency ones, has to maintain the mentioned values and even more achieve suitable landscape integration within the urban context. However, this is a truly complex intervention, as the energy measures implementation could imply either modifying the building envelope or installing new systems.

To support designers in defining renovation measures aimed at improving the energy performances of the protected cultural heritage, the Italian Ministry of Cultural Heritage and Activities and of Tourism – MiBACT has recently developed guidelines [6] adopting the content of the [7]. As clarified in the Guidelines, neither ready to use solutions nor mandatory methodologies are provided. Although the Guidelines provide a collection of suggested measures for historical buildings, it is evident that a wide degree of discretion occurs at the design stage. This is due to the fact that one should simultaneously consider any particular advice from the responsible local institution, as well as any specific, architectural and technical features that merit to be addressed.

The purpose of the study presented in this paper was to define criteria for intervention on school buildings, protected by the Cultural Heritage Code, with the aim of upgrading according to the target nearly Zero Energy Building (nZEB). The study was developed in the frame of a Program Agreements between the Italian Ministry for Economic Development and ENEA, in collaboration with the main national university institutions, while focusing on Energy Efficiency Technologies for Services.

The activities required to carry out the study have featured the definition of a case study based on a survey of school buildings of the Municipality of Milan built over seventy years ago, which is representative of a common historical school building typology. Then, the definition of retrofit measures has been set to meet the nZEB requirements, as defined by the National implementation of the EPBD Recast, duly in compliance with the protection constraints.

The energy simulation of the selected school was conducted on the basis of a certified software that adopts the official National calculation procedure.

The hypotheses of interventions have involved both the building envelope and the building energy equipment in order to meet the performance parameters provided by current legislation. The effectiveness of the various interventions was also economically evaluated, in terms of total annual cost related to energy performance and Net Present Value.

Nomenclature

H'_T	Global mean heat transfer coefficient per external surface unit, W/(m^2 K)
$Asol_{\_sum}/A_{net}$	Equivalent summer solar area per net area unit, ND
$EP_{H,nd}$	Energy need for heating, kWh/m^2
η_H	Overall system efficiency for the heating, ND
η_W	Overall system efficiency for the domestic hot water, ND
$EP_{C,nd}$	Energy need for cooling, kWh/m^2
EP_{gl}	Total systems energy use, kWh/m^2
Q_{Wren}	DHW production covered by renewables, %
Q_{HCWren}	Total thermal energy production covered by renewables, %
P_{PV}	Installed electrical power from renewables, kW

2. Identification of the case study

Through a survey of the school buildings owned by the Municipality of Milan, we identified those built before the World War II. Many of which have formal characteristics in common, except for those of relevant architectural interest, or characterized by peculiar stylistic features.

In all cases, from a technological point of view, the adopted fabric solutions lead to the common practice consistent with the age [8]: load-bearing masonry made of solid clay bricks, tilted wooden beam roofs with tile covering, reinforced concrete and hollow clay mixed floors, (the first floor over unheated basement, the last floor below unheated attic), single glazed windows with wooden or metal frames. Some buildings have been refurbished over time, rarely in the whole building envelope, but purely to meet basic maintenance requirements (such as re-plastering deteriorated walls, re-roofing and partial windows replacement). Among the listed buildings the Primary School located in via Emilio Morosini, 11-13 (Fig. 1) was selected as case study.

Fig. 1.The case study in the urban context.

2.1. Definition of the case study energy simulation model

The evaluation of building energy performance has been carried out according to national legislation, using a certified software in accordance with national standards in force (technical specifications [9]-[14]).

The model of case-study was initially simulated at actual state (case BUILD.act), describing the different thermal zones according to the main building uses (teaching, administrative, distribution, gym and toilet). The energy calculation mode has been set for building use under standardized conditions. The surveyed actual installed power of the lamps (fluorescent) and of the heat emitters (cast iron radiators) have been assumed in the model. The thermal power station nominal data has been halved, since the school building is served by a natural gas based heat production plant, shared with other buildings whose overall volume is equal to that of the case study.

3. Identification of the energy requalification strategies

The nZEB target meeting was pursued by setting the model requirements based on the "1st level of major renovation" foreseen by [2][2], which means that more than 50% of the surface of the building envelope undergoes a renovation and the heating system has to be substituted, with reference to the stricter restrictions provided for 2019.

In order to meet the nZEB requirements, a set of limit values has to be satisfied: the two parameters *global mean heat transfer coefficient and equivalent summer solar area* (for our case study 0.75 W/m^2K and 0.04 respectively) and, based on the ones calculated through the "*reference building*[1]", the indexes *energy need for heating, energy need for cooling and total system energy use*, as well as the system efficiencies for *heating, cooling*[2] *and domestic hot water*.

Moreover, the nZEB target also foresee the compliance with the [15] requirements, related to the minimum mandatory integration of renewable sources. For our case study (public building) it means, thermal side, covering at least 55% of the Domestic Hot Water energy demand and 55% of the global thermal energy demand (DHW, space heating and cooling energy demand), also electrical side, providing a minimum of 55kW of installed power (this value is calculated based on the area of the building plan).

3.1. Energy improvement measures of the building envelope

In order to achieve nZEB target, the actual state simulation model has been implemented starting from the interventions needed to meet the requirements referred to envelope energy performance (case SYST.act/ENV.nZEB).

The improvement of the opaque building envelope resulted by adding a 20 cm layer of expanded polystyrene on the lower surface of the floor over the basement and over the attic floor, a 12 cm layer of fiberglass panels finished with gypsum plasterboard on the inner side of vertical walls, to comply with the protection constraints. Since in case of window substitution the current energy performance requirements refer to frame widths incompatible with the protection constraints of the facades, new internal windows double glazing equipped with low emissivity coatings and argon filled, have been foreseen in addition to the existing ones. Moreover, the installation of internal venetian blinds, on all orientation except for North, had to be included.

3.2. Improvement measures of building energy equipment

In order to assess the economic implications related to building energy equipment improvements necessary to reach the nZEB target, the results of different renovation measures were compared with a baseline scenario consisting in the conventional building refurbishment: substitution of the heating system with technologies similar to those currently installed, including technological implementations necessary to meet the updated regulations. Therefore, the simulation model was firstly updated according to a more efficient adjustment of the thermal plant control system, achieved by the recent mandatory thermostatic valves installation, which is currently lacking in the building.

Therefore, the effect of the conventional substitution of the heating system, adopting thermostatic valves, has been considered for both simulation models, having the building envelope at the actual state (case

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[1] Reference building is defined as a building identical to that in object of study in terms of geometry (shape, volume, floor area, surfaces of building elements and components), orientation, geographical location, use and boundary conditions, with predetermined thermal characteristics and energy parameters.

[2] Not considered in absence of cooling system, as it is for our case study and for public school buildings in general.

ENV.act/SYST.conv.) and satisfying the nZEB requirements (case ENV.nZEB/SYST.conv.). The latter constituted the new reference case for achieving the overall building nZEB target based on the following implementations.

Existing luminaires have been supposed to be replaced with new dimmable ones, providing indoor lighting control based on combined occupancy and level of illuminance sensors (one sensor each six luminaires), and equipped with LED, halving of the current installed power of fluorescent lamps.

In addition, in order to meet the thermal energy systems and renewable sources requirements, the installation of an air to water heat pump has been assumed, instead of the conventional gas based thermal power generator, since it is compatible with the constraint of protection and refers to a technological practice likely to be replicable everywhere.

In order to meet *total system energy use* index, the heat pump installation has been matched to a photovoltaic system having a double area with respect to what is strictly necessary for the electrical renewable requirement (BUILD.nZEB HP+2PV). In fact, to satisfy the 55kW of electrical power from renewables, the installation of a photovoltaic system integrated on the roof has been assumed, as allowed by the [6] covering only one of the two major roof pitches of the building facing the courtyard, to minimize the visual impact from the urban context. Moreover, alternative to the air to water heat pump solution, the possibility to connect to a district heating network has been evaluated. This solution, although not replicable everywhere, was considered since its adoption allows the derogation from the National obligations of thermal renewable sources contribution (BUILD.nZEB DH+PV).

In both cases DHW production system was separately considered, with single unit air source heat pumps instead of the conventional electric boilers currently installed in the toilets, although not mandatory for the elementary school.

3.3. Energy performance assessment

Table 1 summarized energy performance results, obtained by simulating the matrix of the different cases identified with the implementations described above. Energy performance parameters, indexes, efficiencies and percentages of renewables that do not meet the required performance limits are highlighted in bold.

Table 1. Parameters, indexes, efficiencies and contribution from renewables.

		BUILD.act	SYST.act/ ENV.nZEB	ENV.act/ SYST.conv	ENV.nZEB/ SYST.conv	BUILD.nZEB (HP+2PV)	BUILD.nZEB (DH+PV)
$EP_{H,nd}$	[kWh/m^2]	**168.5**	36.8	**168.5**	36.8	36.8	36.8
$EP_{H,nd,Lim}$	[kWh/m^2]	38.3	40.1	38.3	40.1	40.1	40.1
$EP_{C,nd}$	[kWh/m^2]	27.0	28.2	27.0	28.2	28.2	28.2
$EP_{C,nd,Lim}$	[kWh/m^2]	52.1	32.1	52.1	32.1	32.1	32.1
EP_{gl}	[kWh/m^2]	**314.7**	**130.2**	**288.5**	**118.0**	80.2	85.2
$EP_{gl,Lim}$	[kWh/m^2]	76.6	82.5	76.6	82.5	86.2	92.0
H'_T	[W/(m^{2}K)]	**1.92**	0.43	**1.92**	0.43	0.43	0.43
$H'_{T,Lim}$	[W/(m^{2}K)]	0.75	0.75	0.75	0.75	0.75	0.75
Asol'	[-]	**0.09**	0.04	**0.09**	0.04	0.04	0.04
$Asol'_{Lim}$	[-]	0.04	0.04	0.04	0.04	0.04	0.04
η_H	[-]	**0.66**	**0.60**	0.74	0.74	1.53	0.59
$\eta_{H,Lim}$	[-]	0.73	0.73	0.73	0.73	1.38	0.55
η_W	[-]	0.36	0.36	0.36	0.36	5.88	1.03
$\eta_{W,Lim}$	[-]	0.36	0.36	0.36	0.36	1.93	0.80
Q_{Wren}	[%]	**19.42**	**19.42**	**19.42**	**19.42**	85.00	
Q_{HCWren}	[%]	**0.08**	**0.16**	**0.08**	**0.19**	59.55	
P_{PV}	[kW]					117.00	58.50

The set of simulations has been obviously divided into further sub-cases, in order to stress the effects of the single solutions that contributed to the achievement of the nZEB target, with the economic analysis described below.

3.4. The composition of the costs of the interventions and economic analysis of achievable energy performance targets

3.4.1. Economic evaluations

The economic evaluations have been conducted referring to the total annual cost, defined as the sum of the annual cost of building management[3] and maintenance and the annual discounted instalment of initial costs, which is given by the ratio between the cost of the initial investment and the annual discount factor.

The costs of the interventions were determined on the basis of the [16], properly adjusted for including additional costs for the design and construction supervision and for considering high performance technological solutions that were not covered in the common list. Unless otherwise specified in the following descriptions, the maintenance costs foreseen by the [17] have been assumed.

Concerning the annual discount factor, which distributes the investment of initial capital in annual constant installments, the calculation period of 30 years and the interest rate 3% of the baseline scenario provided by [18] have been considered.

Moreover, adopting the variation trend in the cost of energy and of the inflation rate characterizing the previous five years (assumed as 3% and 1% respectively), the Net Present Values (NPV) of different interventions have also been calculated and consequently the Pay-Back Times.

3.4.2. The costs of the interventions

Table 2 shows the costs of the interventions required to meet the nZEB building envelope requirements. With the exception of the likely replacement of the damaged venetian blinds, no maintenance costs were taken into account.

Table 2. The costs required to meet nZEB envelope requirements.

	€/m^2	m^2	€ tot	Maintenance (%)	Maintenance (€/a)
Roof insulation	39.1	2347	91829	0	0
Basement insulation	44.7	2328	104031	0	0
Wall insulation	55.9	5447	304734	0	0
Added windows	326.9	1690	552625	0	0
Venetian blinds	42	1158	48636	0.05	2432
GLOB ENV.nZEB			**1101855**		**2432**

Table 3 shows the costs due to the substitution of conventional thermal energy systems and those related to the enhancement of energy equipment to meet energy performance indexes, efficiencies and obligations of integration of renewable sources towards nZEB target. The costs of the global interventions result in extra costs with respect to the conventional substitution of thermal energy systems.

It is to be pointed out that with respect to current lamps, the new LED luminaires result in a reduced maintenance cost. The higher cost due to the control sensors to be replaced in case of failure (assumed equal to 5% of the 200

[3] *Electricity and natural gas costs were set to 0.052 €/kWh and to 0.20 €/kWh respectively, in consistent with the Municipality data. Concerning the district heating, it has been assumed the price of the main district service in Milan, 0.053 €/kWh. Since the adopted economical approach does not consider incentives, tax deductions, etc., likewise the revenues from the electricity surplus from photovoltaic released to the grid have been referred to the last registered National unique price of 0.056 €/kWh (year 2015).*

provided) will be largely outweighed by the reduction of lamp replacement (LED’s useful life is double compared to fluorescent lamps).

Concerning the District Heating case, it has to be noted that the cost of the intervention only foresees the arrangement of the thermal power station connection, since the provision of the heat exchanger is included in the service. The maintenance cost is constituted by 10.09 €/kW$_t$, deducting the cost avoided for the conventional "third party responsible and periodic checks”, which is already included in the service.

Table 3. Costs of the conventional substitution of thermal energy systems and of the building energy equipment towards nZEB target.

	€/unit	n°	€ tot	Maint. (%)	Maint. (€/a)
Natural gas heat generators	19000	2	38000	0.015	570
Electric boilers (water heating)	270	14	3780	0.01	38
LED luminaires with sensors	162.5	1247	202638		-1056
Heat pumps (water heating)	1630	14	22820	0.04	913
PV south	117000	1	117000	0.02	2340
PV south - north	117000	2	234000	0.02	4680
Heat Pumps Air/Water	50000	2	100000	0.03	3000
District Heating	5000	1	5000		2541
BUILD.nZEB (HP+2PV)			**1619533**		**9361**
BUILD.nZEB (DH+PV)			**1407533**		**6561**

3.4.3. Energy and economic analyses comparison

The economic analyses have been referred to annual primary energy consumptions related to the different energy vectors, calculated in accordance with the energy conversion factors listed in the [2].

The following graphs show the comparison results among the interventions highlighting the relations with corresponding total annual costs.

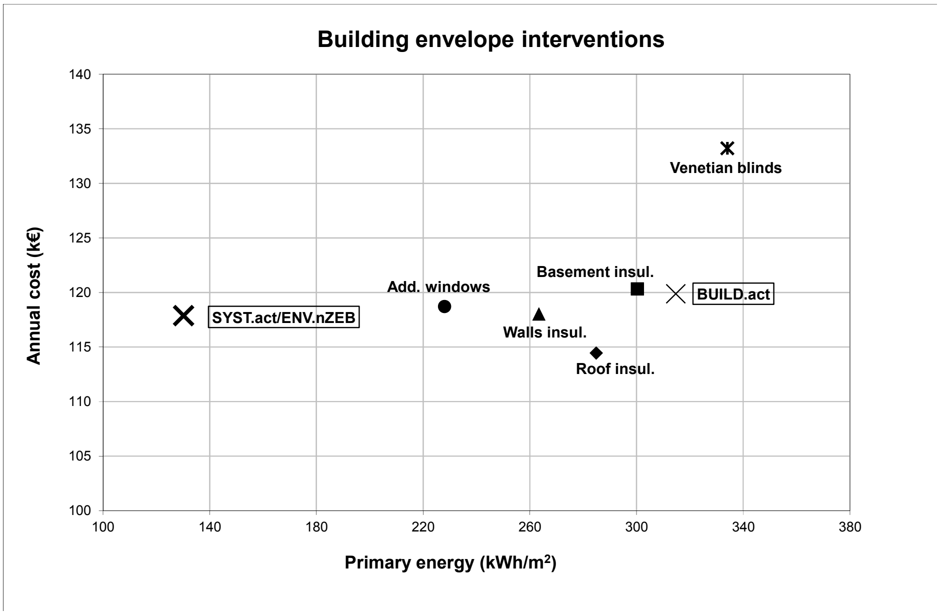

Fig. 2.Building envelope interventions: annual costs and primary energy consumptions.

The first comparison, represented in Fig. 2, shows the results of the interventions necessary for meeting the building envelope nZEB requirements.

Overall building envelope interventions aimed to meet nZEB target requirements (SYST.act/ENV.nZEB) result notably advantageous from the energy point of view, yet, marginally from that of the annual costs.

If we analyze the individual interventions, we can point out that, from one side, the decrease in the consumption of primary energy due to the insulation of the basement will lead to an increase of the annual cost; on the other side, in particular, with the adoption of internal venetian blinds, both the energy consumptions and the annual costs increase. In fact, in absence of cooling system the useful effect of the latter intervention cannot be properly taken into account. Moreover, its negative contribution in the heating balance is oversized due to the limitations of the "standard" energy assessment method: the assigned shading coefficient cannot be differently detailed for the winter period, when the blinds would be probably used only to avoid direct glare from solar source.

The second comparison (see Fig. 3) concerns the results of energy equipment interventions, with respect to the simple "conventional" heating system replacement, in order to meet the performance indexes, energy efficiencies and obligations of integrating renewables of the nZEB target, whereas the building envelope already complies with nZEB requirements.

The graph shows the effectiveness of both photovoltaic sizes and highlights that the LED lamps installation equipped with lighting control sensors proves to be the intervention that gives the largest energy savings associated with the greater reduction of annual costs.

Combining the latter intervention with the heat pumps adoption, with consequent photovoltaic panels' installation on the two roof pitches, does not bring any benefit in terms of primary energy reduction consumptions, but rather a significant increase in the annual costs. The energy advantage due to the photovoltaic energy production counters the greater primary energy consumption of the heat pump.

Differently, the thermal supply from district heating combined with the photovoltaic installation on a single roof pitch proves advantages on both ends.

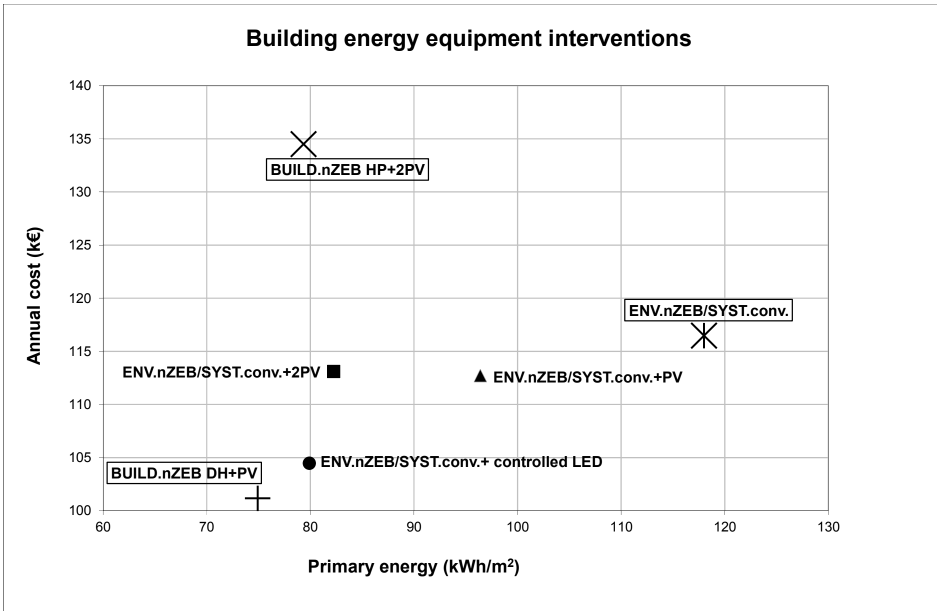

Fig. 3.Building energy equipment interventions: annual costs and primary energy consumptions.

3.4.4. Net Present Value and Pay Back Time on investments

The NPV of the interventions are represented in the following graphs, which also show the PBT of investments. Fig. 4 summarizes the evaluations related to the types of interventions on the building envelope.

The roof insulation allows to reach a positive NPV in the fewest number of years (9), while for the other renovation measures the Pay Back Time is at least twice (walls insulation: 18 years; additional windows: 19 years; basement floor insulation: 21 years).

The overall intervention on the building envelope results in PBT equal to 19 years (SYST.act/ENV.nZEB case).

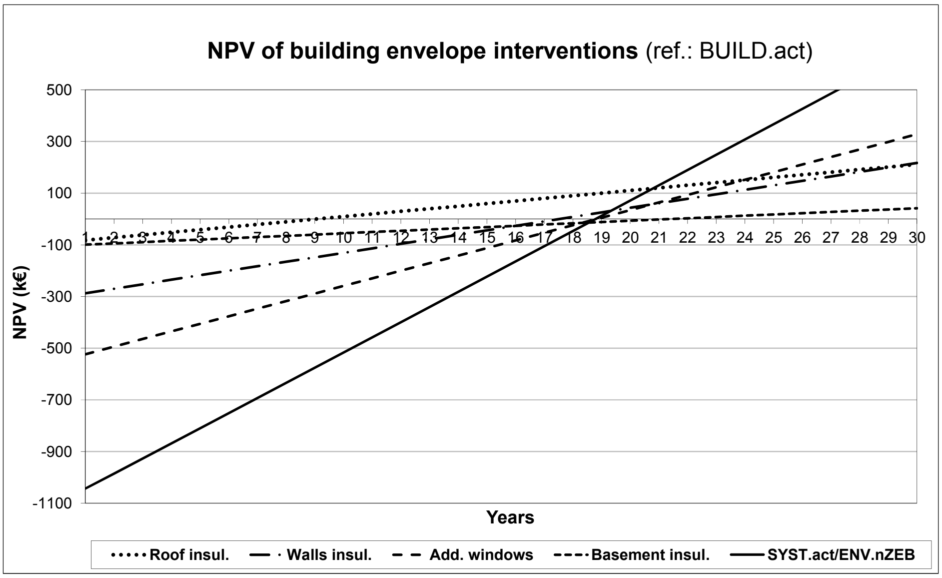

Fig. 4.NPV of building envelope interventions aimed to meet nZEB target requirements.

Fig. 5 highlights PBT due to energy equipment interventions with respect to the simple "conventional" heating system replacement, with the building envelope already complying with nZEB requirements (LED lamps installation equipped with lighting control sensors: PBT=9 years; PV integration on one and two roof pitches: PBT=12 years and 15 years respectively).

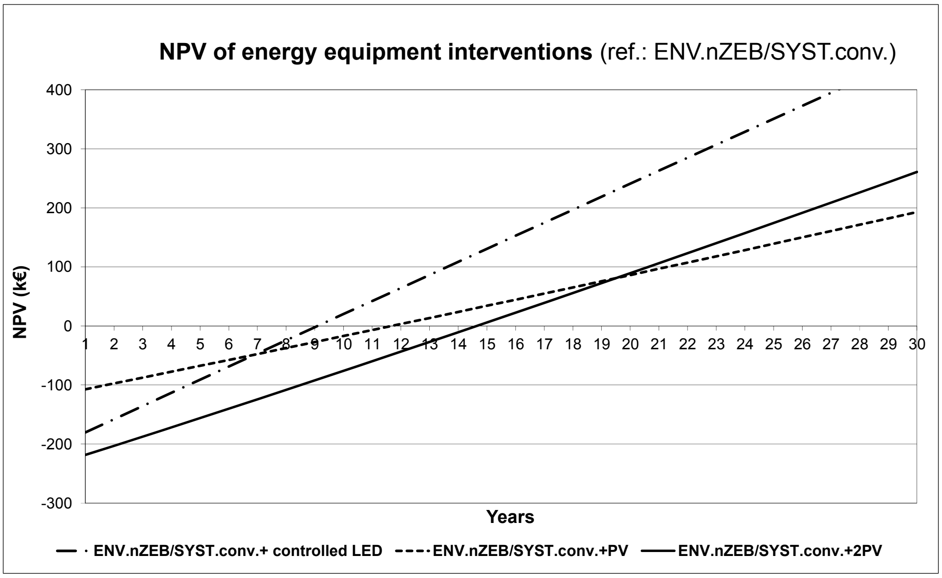

Fig. 5.NPV of energy equipment interventions with respect to building envelope already complying with nZEB requirements.

Fig. 6 shows NPV of overall interventions needed to meet nZEB target requirements related to the two different thermal generations considered: PBT is equal to 17 years for District Heating and 26 years for Heat Pump.

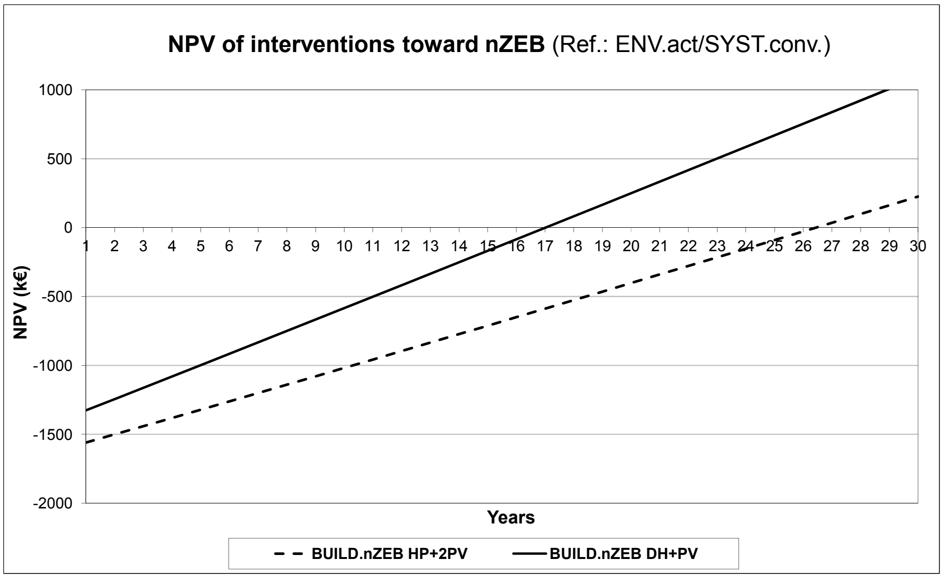

Fig. 6.NPV of overall interventions.

4. Conclusions

The subject of this study was the definition of criteria for intervention on school buildings, protected by the Cultural Heritage Code, with the aim of enhancement according to the target nearly Zero Energy Building.

The selected case-study, which is representative of a common historical school building typology, has been simulated based on a certified software that adopts the official National calculation procedure. The retrofit measures have been set to meet the National nZEB requirements while complying with the protection constraints.

The results demonstrated that the nZEB target could be achieved by retrofitting the building with proven and widespread solutions, compatible with the constraint of protection, while dramatically reducing the primary energy consumption. Nevertheless, the following considerations have to be highlighted. Overall building envelope interventions aimed to meet nZEB target requirements would lead to a 60% reduction in the primary energy consumption, but slightly in that of the annual costs. In fact, the main useful contribution is observed through the insulation of the roof, 9 years of PBT, while the other interventions of envelope insulation imply twice as long. Moreover, since the building is not conditioned during summer (as a primary school, during most of the summer period is unoccupied), the adoption of shading devices seems to be inconsistent and economically ineffective. In addition, because of the "standard" energy assessment limitations in evaluating the windows shading devices performance (it assumes the shading coefficient as constant all over the year), the results are self-defeating.

Then, upgrading the building with overall energy equipment measures needed to entirely meet the nZEB target implies a further reduction of primary energy in the order of 35%. In this frame, the effectiveness of both photovoltaic and LED lamps with lighting control sensors, gives the largest energy savings associated with the greater reduction of annual costs, revealing years of PBT within 15. Differently, the improvement of the conventional heating system replacement decrease the annual cost (13%) only with the particular case of the district heating connection (17 years of PBT), while implying a 15% of increase in the annual cost with reference to a technological solution likely adoptable everywhere, such as air-to-water heat pump (26 years of PBT).

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